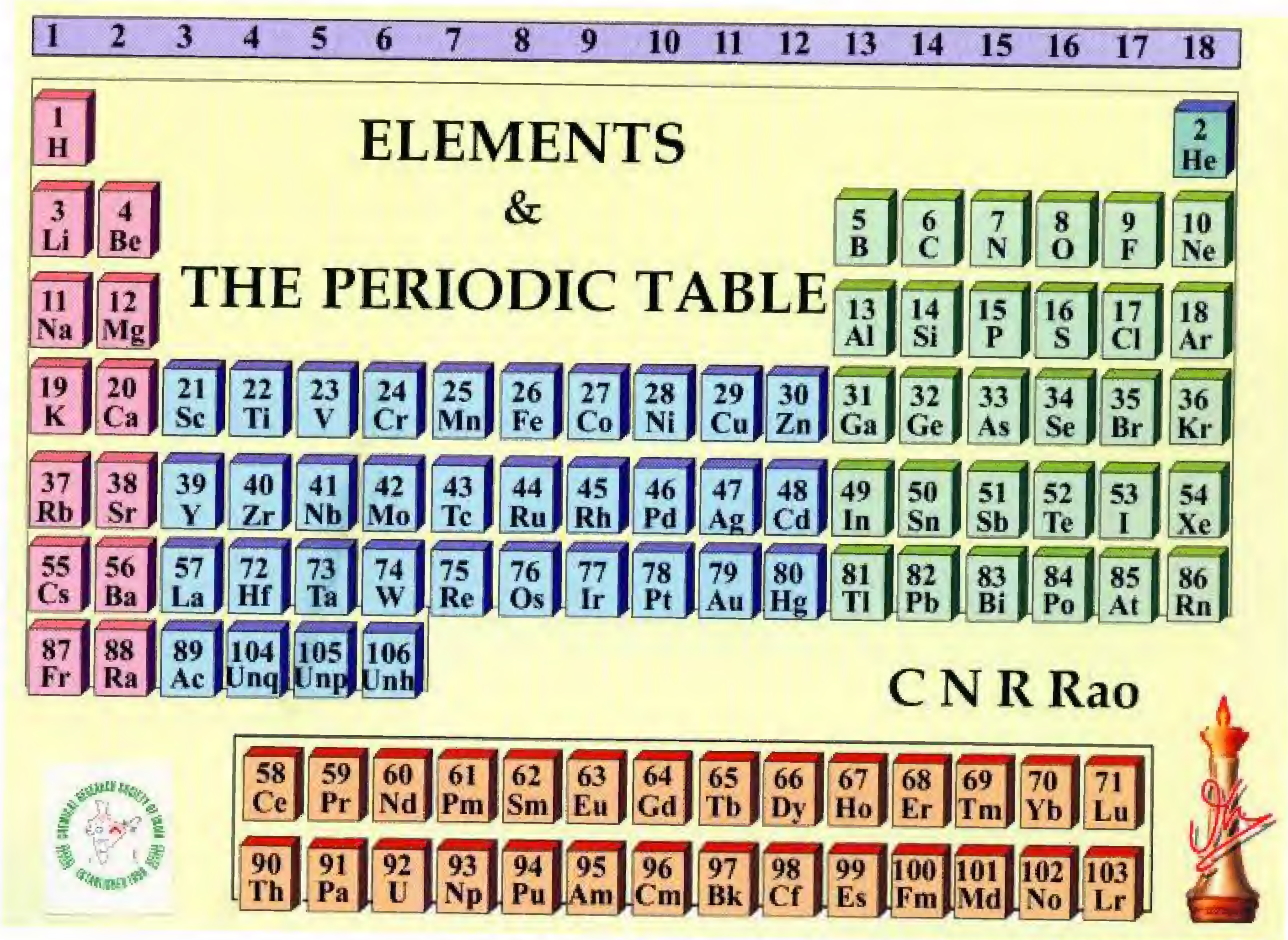

ELEMENTS & THE PERIODIC TABLE

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Elements
&
The Periodic Table

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OBJECTIVES

In this lesson we will try to understand how the idea of elements, and then of the atom, developed over a period of time. We will see how the different elements, as we know them today, can be described in terms of the electronic structure of atoms.

We examine how the need to classify the elements and the ways to classify them, gave birth to the periodic table.

We discuss the important features of the modern periodic table and point out how it provides a basis to explain and predict properties of substances.

There are millions of substances of different shapes and properties.

They are found in the form of
solids **liquids** and **gases.**

However, the amazing fact is that these millions of substances are varied combinations of only less than **100 naturally occurring elements**!!

"What is matter made up of ?"

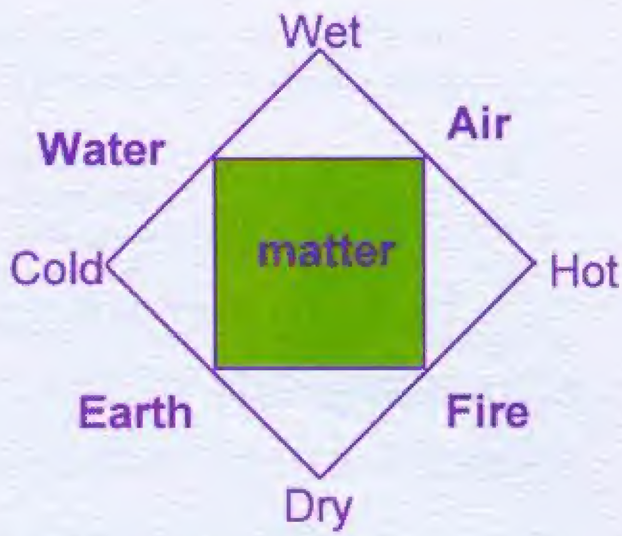
Philosophers of **ancient Greece** and **India** sought an answer to this question centuries before Christ.

Early Greek Idea

Empedocles (500-430 B.C) suggested that **fire, water, air and the earth** constituted the primary elements of matter.

Aristotle (384-322 B.C) agreed with Empedocles's concept of the **four primary elements** constituting matter.

He added a crucial component to this idea--**properties of these elements.**



According to Aristotle, the properties of any particular substance were due to the composition ratio of the four primary elements.

Interestingly, almost an identical concept was developed independently in India during this period (600 to 500 B C)

According to samkhya philosophy, matter was made up of five "bhutas" or elements consisting of akasa (sky), vayu (air), tejas (fire), ap (water) and kshiti (earth).

The **"bhutas"** shared properties like **colour, taste, smell, touch** and at the same time, each "bhuta" had **distinguishing properties** of its own.

The distinguishing properties were **kshiti-smell, ap-coolness, tejas-hotness and vayu-touch.**

The difference in the properties of the same"bhuta class" was due to the difference in the grouping.

The only significant part of the Greek concept of the elements to survive is that elements have distinctive properties.

What is an element ?

This piece of antimony is made up of identical antimony atoms.

Now cut the antimony piece into two
or
break them into flakes
or
grind into powder.

Still, we will find pieces of matter containing identical atoms of antimony.

An element is a substance which cannot be further reduced to a simpler substance by ordinary chemical processes and is made up of atoms of one kind only.

To arrive at this understanding of what an element is, it took many centuries of observation and experiments.

How and when were the elements discovered ?



The **story of elements** is linked to the **story of human civilization.**



From the stone age to modern times, man has used many **metals and their compounds** to suit his needs.

Man learnt to **extract elements from ores**, and fashion them into implements without knowing what an element was.

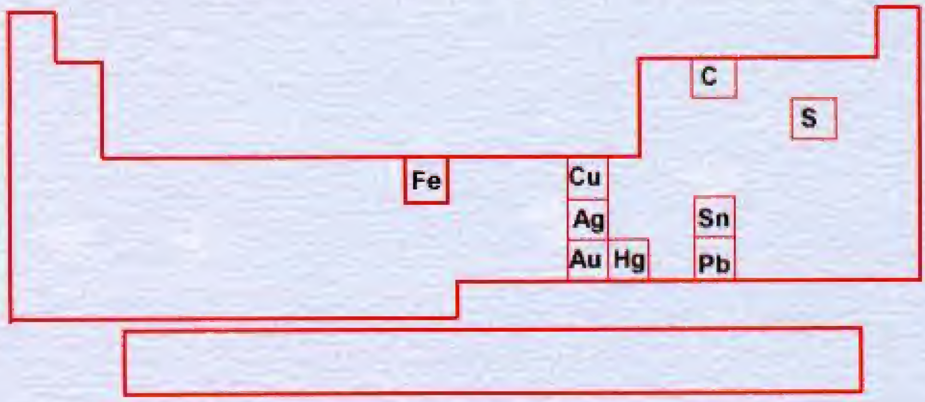
But they were not identified as chemical elements.

Each of these metals was associated with a particular heavenly body.

Sun	Moon	Mars	Venus	Saturn	Jupiter	Mercury
aurum	argentum	ferrum	cuprum	plumbum	stannum	hydrargyrum
Au	Ag	Fe	Cu	Pb	Sn	Hg
☉	☽	♂	♀	♄	♃	☿
gold	**silver**	**iron**	**copper**	**lead**	**tin**	**mercury**

In addition to these seven elements, sulfur and carbon were also known.

If we place these nine elements in their respective positions in the modern periodic table, it would look like this.



Cu Ag Au have similar chemical properties and **Sn Pb have similar chemical properties.**

Middle Ages and the Alchemists

Alchemists are the forerunners of present-day chemists!! They were perhaps the earliest experimentalists.

They tried various experiments to convert base metals into gold by using the "**philosopher's stone**"- an illusionary substance.

While they did not succeed in converting "base" elements to gold, they succeeded in separating and identifying

arsenic
antimony
bismuth

If we place these three elements in the modern periodic table they would look like this:

33 **As** 74.91
51 **Sb** 121.76
83 **Bi** 208.99

Members of a chemical family sharing similar properties !!

Alchemists added three more properties to Aristotle's list of properties.

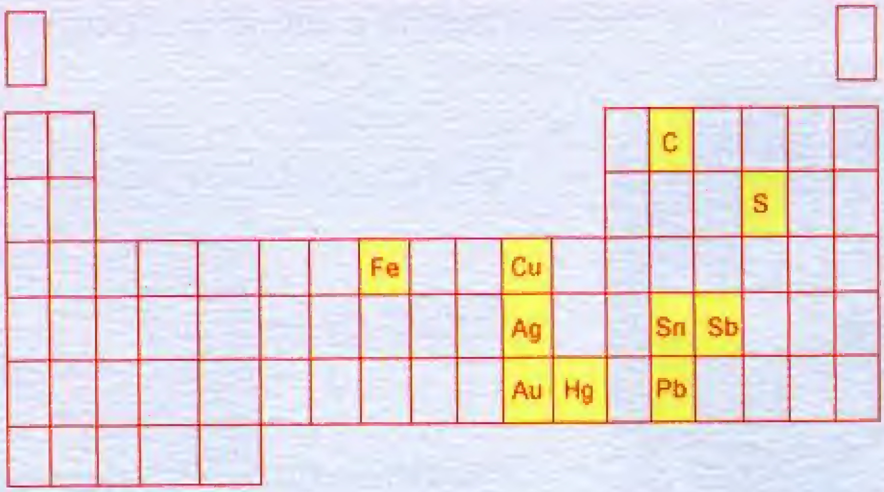
Combustibility (sulfur)

Volatility (mercury)

Incombustibility (chemical salts)

Properties of elements still remained merely abstractions.

Upto the 16th century, only 10 elements were known.



Mercury Hg
Antimony Sb
Silver Ag
Sulfur S
Copper Cu
Carbon C
Lead Pb
Tin Sn
Iron Fe
Gold Au

Modern concept of elements

By 1661, the fundamental difference between a **mixture and a chemical compound** had been understood.

Robert Boyle was the first to reject Aristotle's concept of an element

Boyle argued that fire, water, air, and earth could not be considered as elements because

- they could not combine to form other substances

and

- they could not be separated or extracted from other substances.

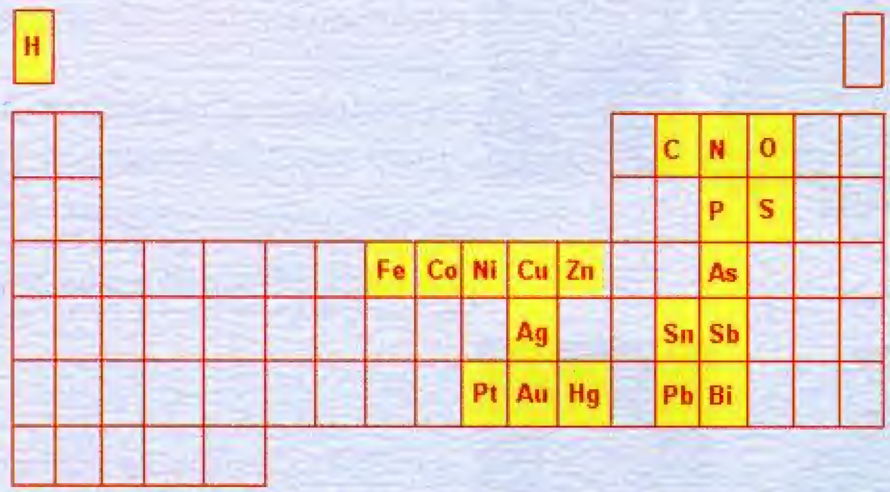
He emphasized the physical properties of elements.

According to Boyle, elements

- were simple, unmixed bodies.
- were not made up of other similar or dissimilar bodies.
- were unique substances.

From this time on, the term **"element "** meant a material substance.

Twenty elements were known by 1775.



Bismuth (Bi) Hydrogen (H) Silver (Ag) Tin (Sn) Gold (Au) Arsenic (As)
Phosphorus (P) Cobalt (Co) Nickel (Ni) Platinum (Pt) Mercury (Hg) Carbon (C) Sulfur (S)
Copper (Cu) Nitrogen (N) Antimony (Sb) Iron (Fe) Zinc (Zn) Oxygen (O) Lead (Pb)

Chemical criteria for identifying elements based on experimental data were established by the middle of the 18th century.

In 1789, **Lavoisier** of **France** published the **first list** of chemical elements.
On the basis of experimental data, his list had 23 elements.

He used **chemical decomposition** as the basis of classification of elements.

In 1807, **Humphrey Davy** of **Britain** added two more elements to the list of known elements- **Sodium and Potassium.**

Need for arranging elements in an order

Advances in chemistry improved the understanding of the properties of the elements.There was a need to arrange the known elements in an order.

To do this, an understanding of the **structure of the atom** became necessary.

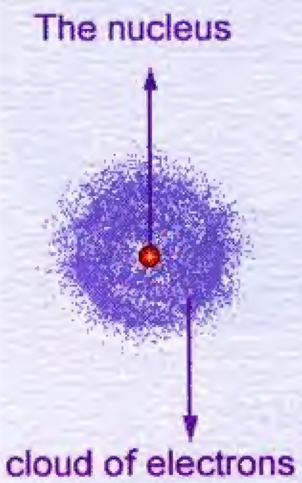
The Modern atom

In1904, **J J Thomson** discovered the **electron.**

The electron
- has negligible mass,
- has **negative charge**,
- and is a **constituent of atoms** of all elements.

The first ideas of the modern atom are due to Lord Rutherford.

The atom has a **positively charged nucleus.**



The nucleus is very small in volume.
It contains positively charged **protons** and **neutrons** without charge.

Protons are, therefore, responsible for the **charge of the nucleus.**

Negatively charged electrons surround the nucleus and occupy most of the volume.

The mass of an atom is entirely due to protons and neutrons.

What is mass number ?

The mass number of an element is the sum of protons and neutrons in the nucleus.

What is atomic number?

The **atomic number** of an element is equal to the **number of protons in the nucleus.**

Atoms are neutral because they have the **same number** of electrons and protons.

Note! The **number of electrons** in a neutral atom is also equal to the **atomic number**.

Niels Bohr proposed that electrons move around the nucleus in **orbits**.

According to Bohr

Each orbit is associated with a **definite energy**.

The energy of electrons can be specified by giving **numbers** to the orbits.

These numbers are called ***principal quantum numbers***.
They have values 1,2,3,......................

As the number increases, the energy of the electron increases.

If an electron jumps from **one orbit to another**, there will be **change in energy.**

For example, if an electron goes from orbit 1 with energy E_1 to orbit 2 with energy E_2, then the change in energy is given by $\mathbf{E_2 - E_1}$

This energy change is accompanied by **absorption of radiation.**

> **The energy of the radiation is given by the equation**
> $E_2 - E_1 = h\nu$ where ν is the frequency of radiation and **h** is the **Planck constant**.
> The value of **h** is 6.626×10^{-34} J s.

The absorption and emission of light due to such electron jumps in atoms have been measured by using **spectrometers.**

It was pointed out by **de Broglie** that electrons have **wave properties** as well

The wave associated with an electron is called an **orbital**.

How do we specify the energies of different electron orbitals ?

To do this, it is necessary to describe electrons or their energies more specifically.

This requires more than one quantum number.

We will first make use of two numbers (quantum numbers) to illustrate how electrons can be individually described.

First we have the **principal quantum number** with values 1,2,3.......... given the symbol "***n***"

Then we define another **quantum number "*l*"**

For each of "*n*", there can be different values of "*l* " varying between 0 and (*n*-1).

Let us see how this works

***n* = 1, " *l* " can only be 0**

***n* = 2, " *l* " can only be 0 or 1**

***n* = 3, " *l* " can be 0, 1 and 2**

***n* = 4, " *l* " = ?**

Electrons with '**l**' = **0, 1, 2, 3**............ are called
s, p, d and f electrons.

We shall now list the different types of electrons (electrons with different energies).

n = 1, 1s

n = 2, 2s,2p

n = 3, 3s, 3p, 3d.

n = 4, 4s, 4p, 4d, 4f.

The maximum number of electrons in a **'s' orbital** is **2**.

The maximum number of electrons in a **'p' orbital** is **6**.

The maximum number of electrons in a **'d' orbital** is **10**.

The maximum number of electrons in a **'f ' orbital** is **14**.

We can now see how electrons can be arranged in atoms with increasing atomic number.

Atomic number	Element	Description of electrons
1	H	$1s^1$
2	He	$1s^2$
3	Li	$1s^2 2s^1$
4	Be	$1s^2 2s^2$
5	B	$1s^2 2s^2 2p^1$
6	C	$1s^2 2s^2 2p^2$
7	N	$1s^2 2s^2 2p^3$
8	O	$1s^2 2s^2 2p^4$

Aufbau principle

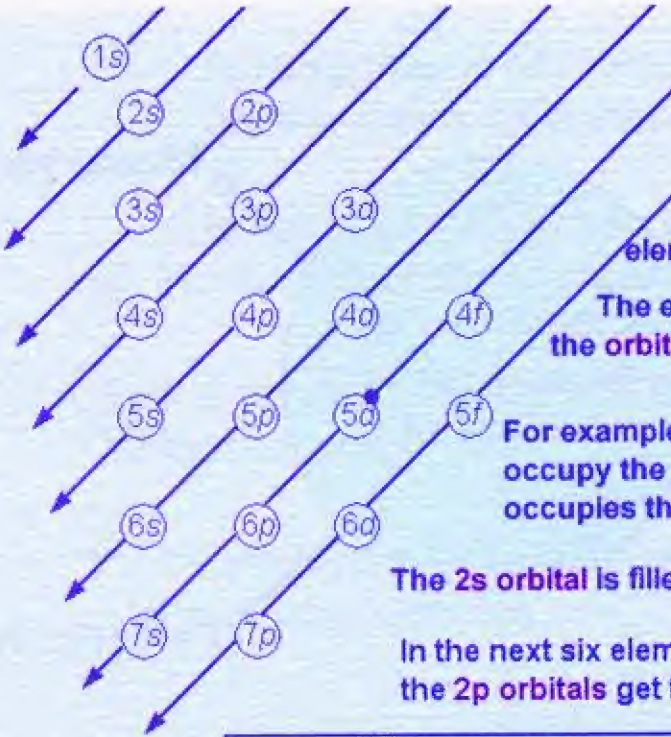
The order of filling of the orbitals is called the aufbau principle.

Aufbau in German means "building up".

Let us find out how the "building up" principle works.

According to this principle,

- electrons should be arranged in the order of their **increasing energies.**
- the order **1s, 2s, 2p, 3s.......** is the order of increasing energy.



This orbital filling diagram helps to understand the electronic configuration of any element in the Periodic table.

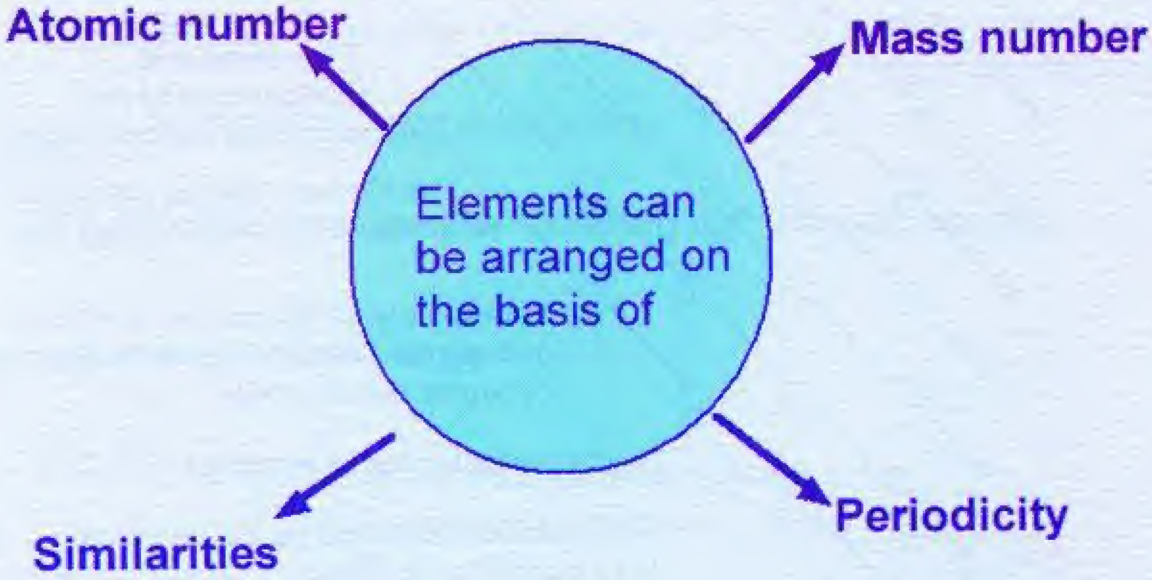
The electron always occupies the orbital with lowest energy first.

For example, in lithium, two electrons occupy the 1s orbital, the third electron occupies the 2s orbital.

The 2s orbital is filled in beryllium ($1s^2$, $2s^2$).

In the next six elements i e. boron to neon, the 2p orbitals get filled.

Note ! after 4s, 3d gets filled up and NOT 4p.



Arrangement of elements on the basis of mass number

Elements were first placed in an increasing order of mass number.

This arrangement was not satisfactory for two reasons:

1. The protons do not determine chemical properties.

2. ? (we will find out later).

Elements arranged on the basis of **similarities of properties.**

It was observed that certain elements, far removed from each other have **similar chemical properties.**

3 Li 6.9	4 Be 9.0											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.3											13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.9	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8

Therefore, such elements had to be **grouped** together.

How is this arrangement helpful ?

Members of a chemical family have similar chemical properties.

Therefore, understanding the chemical behaviour of one element of a family (group) helps to predict the chemical behaviour of the other members of the family.

Two of the well known chemical families are the noble gases and alkali metals.

Noble gases

Helium	2e He
Neon	10e Ne
Argon	18e Ar
Krypton	36e Kr
Xenon	54e Xe
Radon	86e Rn

Alkali metals

3e Li	**Lithium**
11e Na	**Sodium**
19e K	**Potassium**
37e Rb	**Rubidium**
55e Cs	**Cesium**
87e Fr	**Francium**

What do you notice about the **number of electrons** in the noble gases and alkali metals ?

Chemical properties of these two families (groups) are different.

Alkali metals

3e Li
11e Na
19e K
37e Rb
55e Cs
87e Fr

- are excellent conductors of heat and electricity.
- have low melting points in comparison with the melting points of other metals.
- are soft and malleable.
- are reactive.
- react with water to form hydroxides.

Noble gases

2e He
10e Ne
18e Ar
36e Kr
54e Xe
86e Rn

- are the only elements to exist as unbound atoms.
- have low boiling points and densities
- exist as gases at room temperature and pressure.
- do not easily take part in chemical reactions.

We compare below the noble gases and the halogens

Halogens		Noble gases	
		2e He	Helium
Fluorine	9e F	10e Ne	Neon
Chlorine	17e Cl	18e Ar	Argon
Bromine	35e Br	36e Kr	Krypton
Iodine	53e I	54e Xe	Xenon
Astatine	85e At	86e Rn	Radon

What do you notice about the number of electrons in the halogens compared with the corresponding noble gas?

The properties of halogens also differ from the properties of the noble gases. Halogens, like the alkali metals, are reactive.

Halogens		Noble gases		Alkali metals	
Fluorine	9e F	Helium	2e He	3e Li	Lithium
Chlorine	17e Cl	Neon	10e Ne	11e Na	Sodium
Bromine	35e Br	Argon	18e Ar	19e K	Potassium
Iodine	53e I	Krypton	36e Kr	37e Rb	Rubidium
Astatine	85e At	Xenon	54e Xe	55e Cs	Cesium
		Radon	86e Rn	87e Fr	Francium

The number of electrons in a halogen is one electron less than the corresponding noble gas

and

the number of electrons in an alkali metal is one electron more than the corresponding noble gas.

It is convenient to arrange elements on the basis of **periodicity.**

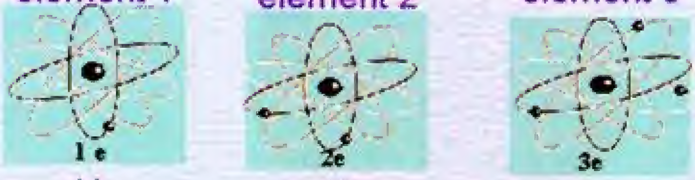
periodicity:
elements display similar properties at regular periods.

Physical properties ← **It can be periodicity of** → **Chemical properties**

Arranging elements based on atomic number.

Elements are numbered according to the **number of protons or electrons** in the atoms.

element 1 element 2 element 3



and so on.

H He Li

Electrons determine the chemical properties of elements.

The chemical properties of an element also provide a basis for arranging elements in an order.

We have seen four possible ways of arranging elements based on:

- ❑ **mass number**
- ❑ **groups**
- ❑ **periodicity**
- ❑ **atomic number**

Let us carefully examine how a **periodic table** is constructed based on these principles.

Early history of the periodic table

By early nineteenth century, about 50 elements had been identified and their properties studied.

Need for arranging elements in a logical manner led to various attempts to produce a **periodic table.**

Dobereiner and the triads

In 1817, Dobereiner discovered that when calcium (Ca), barium (Ba), and strontium (Sr) were listed one below the other they had **similar properties.**

Ca 40.08
Sr 87.63
Ba 137.36

Atomic mass of strontium was close to the average of the atomic masses of calcium and barium

and

the properties of strontium were also an average of the properties of calcium and barium.

Dobereiner was the first

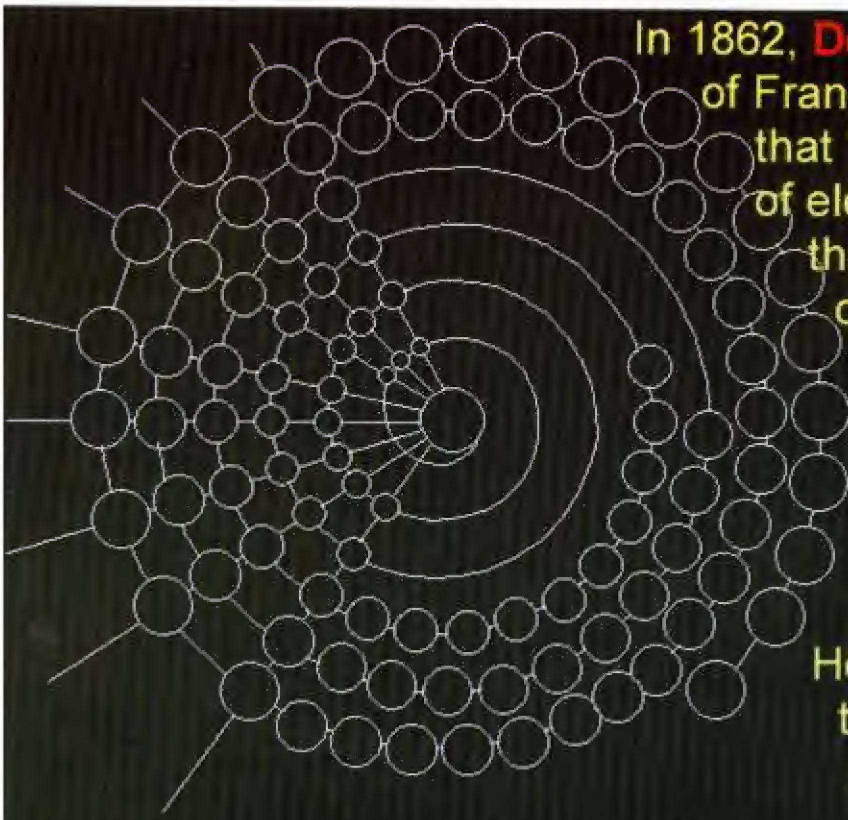
- to identify the **"triads"**

and

- to use the **atomic mass** as the basis for grouping.

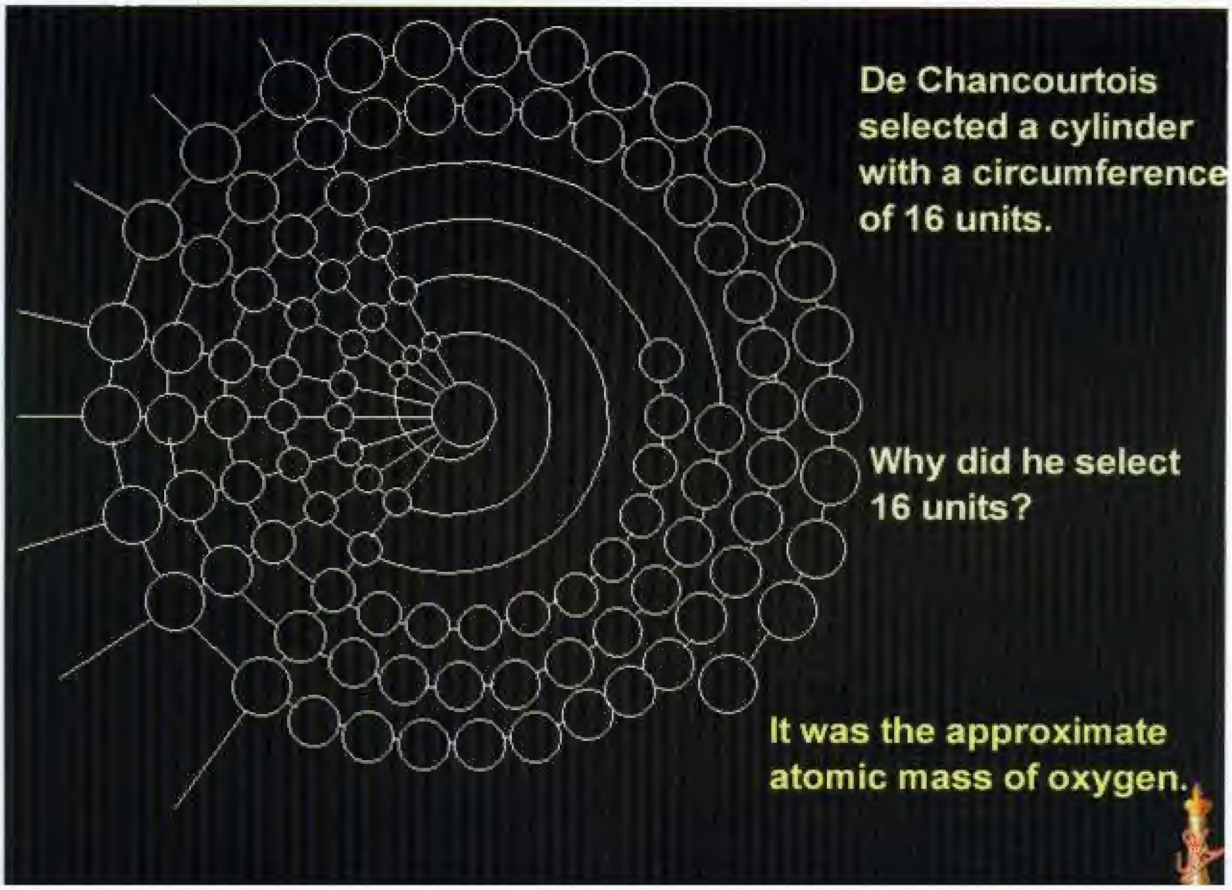
By 1829, two more triads were discovered.

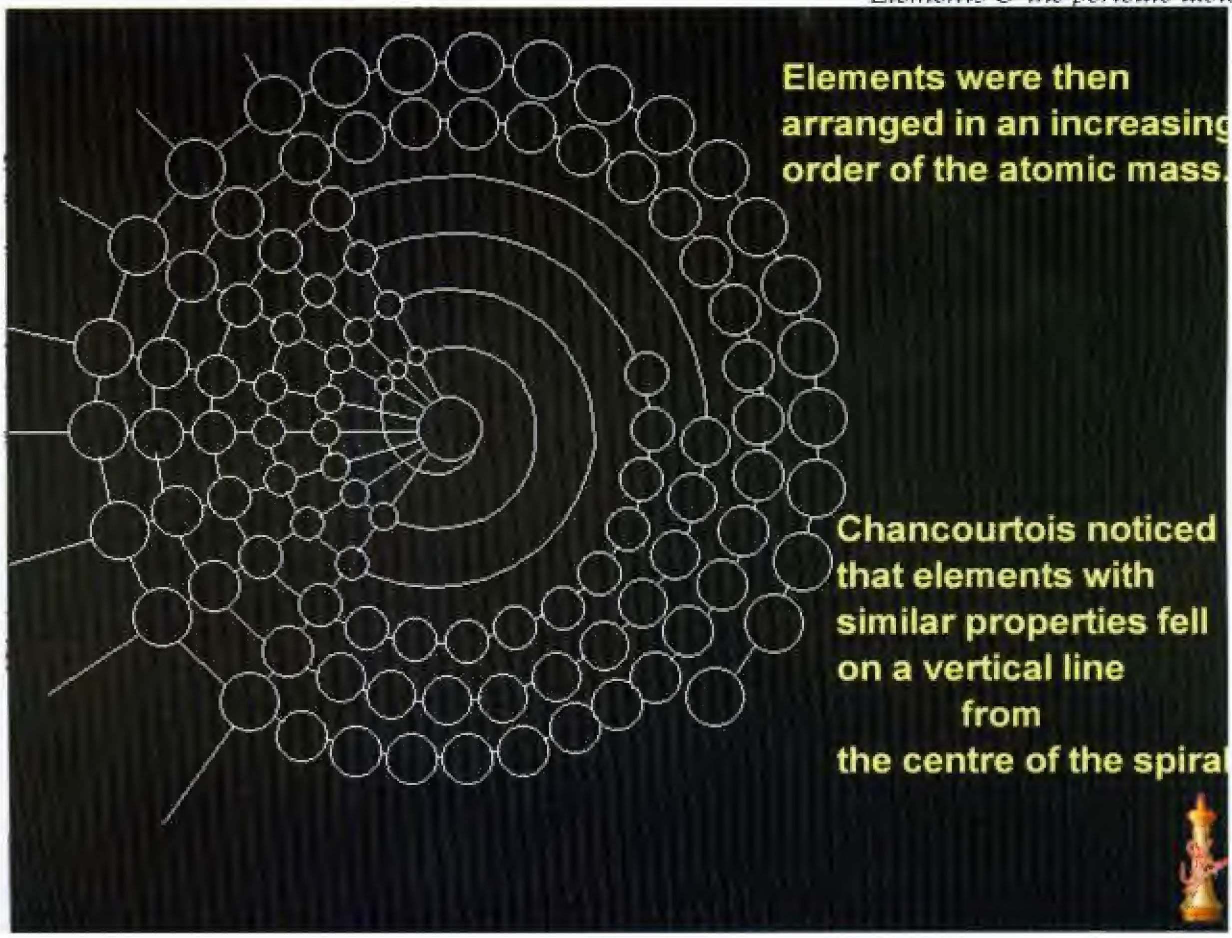
Cl ?	Chlorine		Lithium	Li 6.94
Br ?	Bromine	and	Sodium	Na 22.991
I ?	Iodine		Potassium	K 39.1



In 1862, **De Chancourtois** of France proposed that "the properties of elements are the properties of numbers".

How did he come to this important conclusion?


De Chancourtois
selected a cylinder
with a circumference
of 16 units.
Why did he select
16 units?
It was the approximate
atomic mass of oxygen.


Elements were then
arranged in an increasing
order of the atomic mass.
Chancourtois noticed
that elements with
similar properties fell
on a vertical line
from
the centre of the spiral

In 1864, **Newlands** selected hydrogen, lithium, beryllium, boron, carbon, nitrogen and oxygen as the **first seven elements.**

H 1	Li 2	Be 3	B 4	C 5	N 6	O 7
F 8	Na 9	Mg 10	Al 11	Si 12	P 13	S 14
Cl 15	K 16	Ca 17	Cr 18	Ti 19	Mn 20	Fe 21

He found that when these elements were serially numbered as 1,2,3.....7,and arranged in order, the properties of the eighth element was repeated as the eighth note in the musical notes.

Based on this observation Newlands postulated "the Law of Octaves".

"The eighth element, starting from a given one is a kind of repetition of the first, like the eighth note of an octave in music." Newlands

What was the major drawback of "the Law of Octaves" ?

It was good only for the first 17 elements.

H 1	Li 2	Be 3	B 4	C 5	N 6	O 7
F 8	Na 9	Mg 10	Al 11	Si 12	P 13	S 14
Cl 15	K 16	Ca 17	Cr 18	Ti 19	Mn 20	Fe 21

Newland's contributions were the following :

He was the first

- **to use numbers in a serial order**

  and

- **to predict periodicity.**

Mendeleyev: Father of the modern periodic table.

In 1869, Mendeleyev, the great Russian chemist published the first version of his periodic table.

	I	II	III	IV	V	VI	VII	VII
1	Li	Be	B	C	N	O	F	
2	Na	Mg	Al	Si	P	S	Cl	
3	K	Ca	*	Ti	V	Cr	Mn	Fe Co Ni
	Cu	Zn	*	*	As	Se	Br	
5	Rb	Sr	Y	Zr	Nb	Mo		

Group

Period

Periods are "rows" and groups are "columns".

	I	II	III	IV	V	VI	VII	VII
1	Li	Be	B	C	N	O	F	
2	Na	Mg	Al	Si	P	S	Cl	
3	K	Ca	*	Ti	V	Cr	Mn	Fe Co Ni
4	Cu	Zn	*	*	As	Se	Br	
5	Rb	Sr	Y	Zr	Nb	Mo		

Group

Period

How was Mendeleyev's classification of elements an improvement over the earlier versions?

While earlier periodic tables focussed on a single observed characteristic, Mendeleyev correlated all the known and observed features such as **periodicity, triads (groups) and chemical properties.**

Mendeleyev first listed the known elements in an **ascending** order of their **atomic mass.**

1	Li	Be	B	C	N	O	F
2	Na	Mg	Al	Si	P	S	Cl

Each row (period) had seven elements.

When each row (period) started, the first element in this row (period) had similar properties as the first element in the previous row (period).

As hydrogen did not fit into the pattern, Mendeleyev (and also Meyer earlier) started the first row with lithium.

What are the outstanding features of Mendeleyev's Periodic Table ?

Period →

Group ↓

I	II	III	IV	V	VI	VII	VII
Li	Be	B	C	N	O	F	
Na	Mg	Al	Si	P	S	Cl	
K	Ca	*	Ti	V	Cr	Mn	Fe Co Ni
Cu	Zn	*	*	As	Se	Br	
Rb	Sr	Y	Zr	Nb	Mo		

Notice the gaps left in certain groups.

Mendeleyev

- **arranged the known elements in a tabular form.**
- **numbered the elements according to their atomic mass (mass number)**
- **arranged them in an increasing order of the atomic mass.**
- **did not place odd elements in the main groups (Fe, Co, Ni).**

Why did Mendeleyev leave gaps in his periodic table?

When Mendeleyev arranged the elements, he had to skip places to maintain the similarity in properties of the elements in the vertical columns (groups).

He was certain that there were **missing elements** (elements that were yet to be discovered).

For example, in group IV (the carbon group) he knew that **tin** could not occupy the place immediately below **silicon.**

He left a gap for the element that was yet to be discovered and called this element **eka-silicon.**

By studying the properties of the elements in this group, he was able to predict the properties of eka-silicon.

In 1886, Winkler, a German scientist, discovered the missing element and named it *germanium* !

Properties of *eka-silicon* predicted by Mendeleyev		Properties of *germanium*
Colour	light grey	dark grey
Atomic mass	72	72.6
Density	5.5	5.47
Atomic volume	13	13.2
Oxide	XO_2 High melting point Density 4.7g cm^{-3}	GeO_2 Melting point >1000°C Density 4.703g cm^{-3}
Chloride	Boiling point <100°C Density 1.9g cm^{-3}	Boiling point 86.5°C Density 1.887g cm^{-3}

Mendeleyev also predicted two more elements between **aluminium** and **yttrium.**

eka-boron
(scandium discovered in 1879 by Lars Nilson of Scandinavia).

eka-aluminium
(gallium **discovered in 1875 by Lecoq de Boisbaudran of France).**

B
Al
eka-boron
eka-aluminium
Y

He summed up his observations as
Mendeleyev's Periodic Law.

> **The properties of elements vary periodically with the atomic mass.**

What were the drawbacks of Mendeleyev's Periodic Table?

Like Newland's Law of Octaves, Mendeleyev's Law could not satisfactorily explain the positions of all the elements (for example the positions of tellurium and iodine)

and

there was no place for noble gases.

In spite of the serious drawbacks, a modern version of Mendeleyev's periodic table was used for nearly 50 years.

Group 0	I a b	II a b	III a b	IV a b	V a b	VI a b	VII a b	VIII
	H1							
He2	Li3	Be4	B5	C6	N7	O8	F9	
Ne10	Na 11	Mg 12	Al 13	Si 14	P 15	S 16	Cl 17	
Ar18	K 19 Cu 29	Ca 20 Zn 30	Sc 21 Ga 31	Ti 22 Ge 32	V 23 As 33	Cr 24 Se 34	Mn 25 Br 35	Fe 26,Co 27,Ni 28
Kr 36	Rb 37 Ag 47	Sr 38 Cd 48	Y 39 In 49	Zr 40 Sn 50	Nb 41 Sb 51	Mo 42 Te 52	Tc 43 I 53	Ru 44,Rh 45,Pd 46
Xe 54	Cs 55 Au 79	Ba 56 Hg 70	57-71 Ti 81	Hf 72 Pb 82	Ta 73 Bi 83	W 74 Po 84	Re 75 At 85	Os 76,Ir 77, Pt 78
Rn 86	Fr 87	Ra 88	Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94,An 95, Cm 96

Discovery of Noble Gases

Mendeleyev had no clue of the existence of noble gases.

While studying the spectrum of the light from the chromosphere during a total solar eclipse on August 18 in Guntur, India in 1868, the French astronomer Janssen observed brilliant yellow lines which came from an unknown element.

The element was named Helium - from Helios (the sun).

Discovery of helium was purely accidental!

It took 27 years more before helium was discovered on earth.

After 1894, Lord Rayleigh, Ramsay and Travers in England discovered other noble gases.

Ramsay isolated a gas unknown till then.

This gas

- had no colour,
- had no odour,
- had no taste,
- did not react chemically with other elements.

Ramsay had no hesitation in picking a name for this element.

He called it "argon" (lazy in Greek).

Is there argon on other planets?

Ramsay and Travers discovered neon (new), krypton (hidden) and xenon (stranger).

Ernst Dorn of Germany discovered the last element of this group - radon.

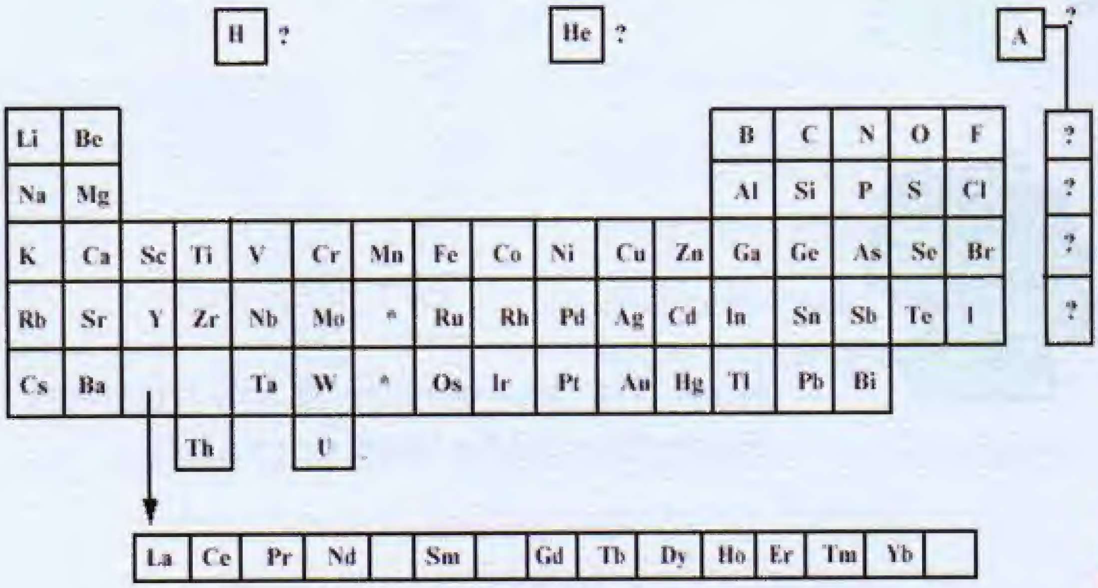
Ne
He
Ar
Kr
Xe
Rn

Now the last group of the modern Periodic Table was complete.

Uses of noble gases

The modern periodic table based on atomic numbers owes its origin to Henry Moseley (1914).

With the various discoveries, the arrangement of elements in the periodic table changed to something close to what we have today.



What are the advantages of arranging elements on the basis of atomic numbers?

- The number of **electrons increases** by the **same number** as the **increase** in the **atomic number.**
- As the number of **electrons increases**, the electronic structure of the atom changes.
- The filling up of the electrons in atoms is done according to the **aufbau principle.**
- Electrons in the **outermost shell of an atom** determine the **chemical properties** of the element.

"The properties of elements vary periodically on the basis of their atomic numbers".

How is the modern Periodic Table useful in understanding the relationships of elements?

Before finding the answer to this question, let us first understand the main features of the modern Periodic Table.

1 H 1.0																	2 He 4.0
3 Li 6.9	4 Be 9.0											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.3											13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.9	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc 99	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La [illegible]	72 Hf 178.5	73 Ta 181.0	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209	84 Po 210	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	89 Ac 227	104 Unq 261	105 Unp 262	106 Unh 263												

Lanthanides	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm 147	62 Sm 150.4	63 Eu 152	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173	71 Lu 175
Actinides	90 Th 232	91 Pa 231	92 U 238.1	93 Np 237	94 Pu 242	95 Am 243	96 Cm 247	97 Bk 245	98 Cf 251	99 Es 254	100 Fm 253	101 Md 256	102 No 254	103 Lr 257

● : Atomic number

● : mass number

Elements are arranged in horizontal rows (periods) and vertical columns (groups).

There are 7 periods and 8 groups in all.

period →

group ↓

	I	II											III	IV	V	VI	VII	O
1	1 H 1.0																	2 He 4.0
2	3 Li 6.9	4 Be 9.0											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
3	11 Na 23.0	12 Mg 24.3											13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
4	19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.9	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
5	37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc 99	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57 La [illegible]	72 Hf 178.5	73 Ta 181.0	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209	84 Po 210	85 At 210	86 Rn 222
7	87 Fr 223	88 Ra 226	89 Ac 227	104 Unq 261	105 Unp 262	106 Unh 263												

Lanthanides	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm 147	62 Sm 150.4	63 Eu 152	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173	71 Lu 175
Actinides	90 Th 232	91 Pa 231	92 U 238.1	93 Np 237	94 Pu 242	95 Am 243	96 Cm 247	97 Bk 245	98 Cf 251	99 Es 254	100 Fm 253	101 Md 256	102 No 254	103 Lr 257

Elements are arranged in an increasing order of atomic numbers in the periods.

All periods do not have the same number of elements.

period

group

	I	II											III	IV	V	VI	VII	O
1	1 H 1.0																	2 He 4.0
2	3 Li 6.9	4 Be 9.0											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
3	11 Na 23.0	12 Mg 24.3											13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
4	19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.9	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
5	37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc 99	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 181.0	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209	84 Po 210	85 At 210	86 Rn 222
7	87 Fr 223	88 Ra 226	89 Ac 227	104 Unq 261	105 Unp 262	106 Unh 263												

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Actinides	90 Th 232	91 Pa 231	92 U 238.1	93 Np 237	94 Pu 242	95 Am 243	96 Cm 247	97 Bk 245	98 Cf 251	99 Es 254	100 Fm 253	101 Md 256	102 No 254	103 Lr 257

The first period has only two elements (Hydrogen and Helium)

The second and third periods have eight elements each.

The fourth, fifth and the sixth have eighteen elements each.

7th period is an incomplete period.

1 H 1.0																	2 He 4.0
3 Li 6.9	4 Be 9.0											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.3											13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
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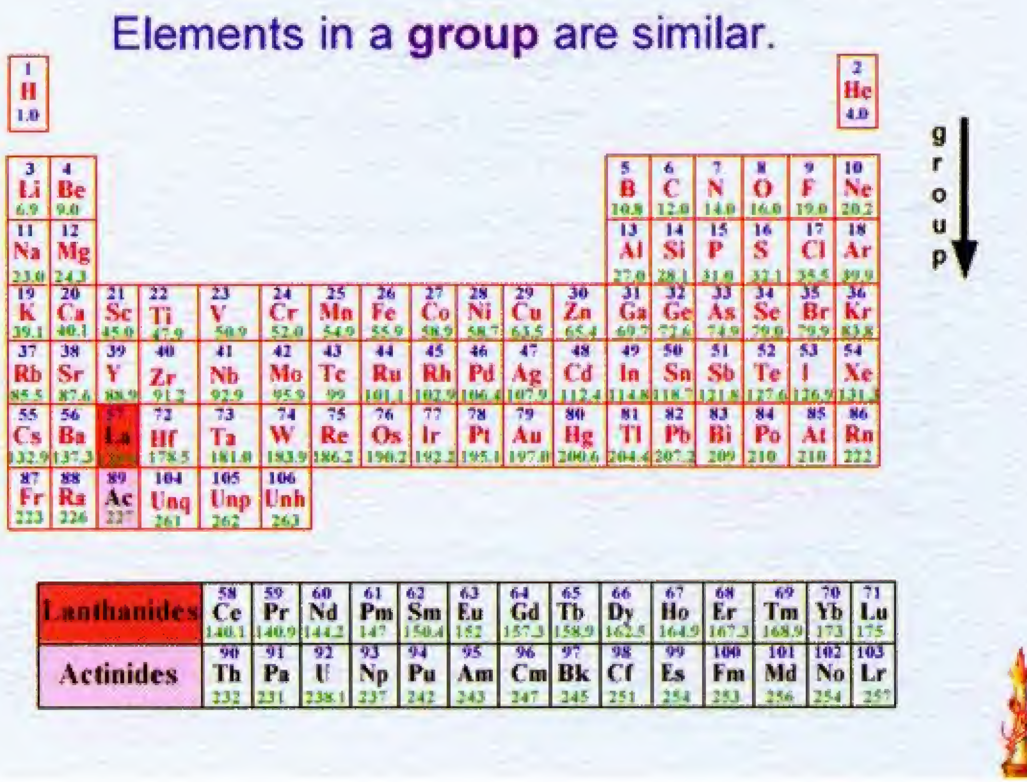
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 181.0	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209	84 Po 210	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	89 Ac 227	104 Unq 261	105 Unp 262	106 Unh 263												

Space for accommodating elements yet to be discovered is provided in this period.

Lanthanides	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm 147	62 Sm 150.4	63 Eu 152	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173	71 Lu 175
Actinides	90 Th 232	91 Pa 231	92 U 238.1	93 Np 237	94 Pu 242	95 Am 243	96 Cm 247	97 Bk 245	98 Cf 251	99 Es 254	100 Fm 253	101 Md 256	102 No 254	103 Lr 257



About the author

C. N. R. Rao is the National Research Professor, Linus Pauling Research Professor at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) and honorary professor at the Indian Institute of Science (IISc). He is an author of 1400 research papers and has written or edited 43 books dealing with spectroscopy, solid state and materials chemistry, superconductivity, nanomaterials and such topics. Some of his books are meant for school and college students. He has received 48 honorary doctorate degrees from Indian and foreign universities. He is a member of most of the major science academies including the Royal Society (London) and U. S. National Academy of Sciences, as well as French, Japan and Pontifical Academies.

C. N. R. Rao has received numerous prizes and medals of which mention must be made of the Marlow medal of the Faraday Society (1967), Bhatnagar Prize (1968), Einstein gold medal of UNESCO (1996), Hughes medal (2000) as well as the Royal medal (2009) of the Royal Society (London). He is the first recipient of the India Science Award of the Government of India (2005) and received the Dan David Prize for science in the future dimension in 2005 for his work on advanced materials. The August-Wilhelm-von-Hoffmann Medal (2010) has just been conferred by the German Chemical Society.

He was conferred the Order of Scientific Merit (Grand-Cross) in 2002 by the President of Brazil, and the Chevalier de la Légion d'Honneur by the President of France in 2005. He has been a distinguished professor at the Universities of Oxford, Cambridge and California. He was President of the International Union of Pure and Applied Chemistry.